NOTES ON STELLAR CLASSIFICATION.

IN all my early work at Kensington (1887) on the classification of stars according to their spectra, the best basis for a classification was chiefly considered. The data available were the chemical facts obtained by a detailed inquiry into the chemical origins of the various lines and flutings, using higher dispersion and more laboratory work than were employed in other observatories.

The first and most important result obtained was that it was found necessary to divide the stars into two groups, one set increasing their temperatures while in the other the temperature was running down.

This, indeed, added a *physical* difference to the chemical ones, and there was another, for on the meteoritic hypothesis the stars getting hotter were sparse swarms of meteorites being vaporised, while those getting colder were rapidly condensing into solid bodies.

These were fundamental changes of front. Up to that time only a line of decreasing temperature had been considered. Passing over the earlier classification of Rutherfurd (1863), which was only modified by Secchi (1867), though by those ignorant of the subject he is credited with the origination of it, I may mention that in 1873 I referred to the question of temperature in a Bakerian Lecture,[1] and in 1874 Vogel brought out a considerable classification. This was also based upon a line of descending temperatures. On this classification I wrote in another Bakerian Lecture (1882)[2]:—

"The idea which underlies the classification is that a star of Class I. on cooling becomes a star of Class II., and that a star of Class II. has as it were a choice before it of passing to Class III*a*. or Class III*b*. Thus under certain conditions its spectrum will take on the appearance of Secchi's third type, Class III*a*. (Vogel); in certain other conditions it will take on the appearance of Secchi's fourth type, Class III*b*. (Vogel). There is now, however, no doubt whatever that Secchi's Class III., represents stars in which the temperature is increasing, and with conditions not unlike those of the nebulæ—that is to say, the meteorites are discrete, and are on their way to form bodies of Class II. and Class I. by the ultimate vaporisation of all their meteoric constituents. There is also no doubt that the stars included in Class III*b*. have had their day; and that their temperature has been running down, until owing to reduction of temperature they are on the verge of invisibility brought about by the enormous absorption of carbon in their atmospheres."

"Pechüle was the first to object to Vogel's classification, mainly on the ground that Secchi's types III. and IV. had been improperly brought together; and my work has shown how very just his objection was, and how clear-sighted was his view as to the true position of stars of Class III*b*."

Prof. Keeler wrote in 1894[3] "Lockyer's system of stellar classification provides for both an ascending and a descending branch of the temperature curve, and in this respect it certainly has advantages over other systems which claim to have a rational basis."

Prof. Frost[4] thus alludes to it: "Many spectroscopists are unwilling to admit that the only course of stellar development is along a line of descending temperature." He does not name the "many spectroscopists," but he adds: "The further question may be raised—Is it not possible that a celestial body, after it has reached the condition in which we may define it as a star, may twice be red and exhibit a spectra of the third type, once in its youth and again in its old age?"

In my papers are many statements giving the answer to this question, years before Prof. Frost put it.

In the Bakerian Lecture (1888) I published a temperature curve with ascending and descending arms, along which stars could be arranged according to their swarm- and condensing-conditions and their temperature as revealed by the spectra. On it were rearranged stars as classified by Vogel and stars with bright lines and nebulæ. Another curve was given in the catalogue of 470 of the brighter stars which I afterwards published in 1902, in which I classified stars only, giving to each group a distinctive name.

Of the stellar spectra used, some had been photographed at the Solar Physics Observatory and others by Mr. McClean at the Cape and Tunbridge Wells.

A few years after the publication of Vogel's memoir the work of classification was taken up at Harvard. The first one adopted was an alphabetical, from A and B onwards in one line. This we may mark as H.1.

At about the same time (1888) that I published my temperature curve at Kensington, the classification of northern stellar spectra in special new groups was being carried on at Harvard by Miss Maury as part of the Henry Draper Memorial. The classification was on one line of temperature in groups numbered from i to xxii. (H.2.).

But Miss Maury did not content herself with the group classification; over and above her twenty-two groups of spectra she gave us three main divisions of stars depending upon the characteristics of the individual lines. Here we find a physical touch superadded. In Division *a* were included lines narrow and clear, in *b* lines relatively wide and hazy, and in *c*, among other conditions, unusually intense metallic but not solar lines. I found these divisions of the utmost value to me when I was preparing my classification.

The Southern stars were undertaken by Miss

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[1] Phil. Trans., vol. clxiv., p. 292.

[2] Proc. R.S., vol. xliv., p. 1.

[3] "Ast. and Ast. Phys." 1894, p. 60.

[4] "Astronomical Spectroscopy," p. 318. 1894.

Cannon, who employed H.1., but some groups were discarded and stars between F and G, for instance, were classed as F5G or F8G. We may mark this as H.3.

The work of Harvard is monumental; tens of thousands of stars have been classified so far as small dispersion can do it, but obviously a straight line, instead of a curve of ascending and descending temperatures, has been followed in the three classifications used one after the other, and in all, if my views are sound, stars of vastly different constitution, sparse swarms and condensed stars, are called by the same name.

A subject of great regret is that, as this is the only large scale classification extant, it is now being used to deal with questions in which it is vital that stars differing in physical constitution shall *not* be classed together; in which such a mixing invalidates the conclusions arrived at in such inquiries.

In the last authoritative book published on these matters Prof. Eddington writes:—"From time to time there are indications that the Draper classification has not succeeded in separating the stars into really homogeneous groups. According to Sir Norman Lockyer there are stars of ascending temperature and of descending temperature in practically every group; so that, for example, the stars enumerated under K are a mixture of two classes, one in a very early, the other in a late stage of evolution."

Prof. Russell, a diligent worker on the characteristics and spectra of stars, has written as follows:—

"I have endeavoured . . . to set before you the present state of knowledge concerning the real brightness, masses, densities, temperatures and surface brightness of the stars, and to sketch the theory of stellar evolution to which the study of these things has led me. This theory is inconsistent with the generally accepted view. Its fundamental principle is identical with that of Lockyer's classification."

Prof. Russell objects to the principles on which I have placed stars in the different groups but that is another, and less important, story, which will be dealt with later.

Prof. Ludendorff[5] has recently provided a case in point; he has discussed Prof. Campbell's results on radial velocities and stellar types based upon the Harvard classification. Difficulties were met with. Dr. Ludendorff points out that these are avoided and that a distinct differentiation of the velocities is obtained if the stars are arranged in the order of ascending and descending temperatures. Of the sixty-three stars selected by Campbell, eighteen are contained in my classification; of these ten are on the ascending arm, and the velocities are all +; the remaining eight are on the descending arm, and the velocities, with one exception, are −. The exception is a star very near the top of the curve.

In arranging the programme of work for the Hill Observatory, the first place has been assigned to the continuation of the catalogue of the bright stars classified on my hypothesis (of two groups of stars, one increasing, the other decreasing their temperature), so that the 470 we already have may be as soon as possible increased to 1000, which will give us a broader base.

I have also occupied some time in considering stars varying from the normal condition dealt with in my published classification. These are:—

Stars with bright lines.
Variable stars with bright lines.
Variable stars without bright lines.
Double stars without bright lines.

The object of my inquiry was to ascertain whether further generalisations were suggested as regards the arm of the curve on which these stars should be most probably found, irrespective of their chemical constitution on which my classification was founded.

This further inquiry was based on my hypothesis[6] that the bright lines in variable stars were due to collisions between meteor swarms. Düner has shown that in Class III*a* (Antarian), of 297 stars 44 were variables, that is, 1 in 7. I found[7] in 1894 that in β Lyræ two bodies resembling Rigel and Bellatrix were involved. This lands us in the Crucian stage, nearly at the top of the ascending arm.

When we deal with variable stars without bright lines (eclipsing variables), the light curves show that we are dealing no longer with swarms, but with bodies with discs and therefore with photospheres, and therefore again approaching the solar condition. Now the best known variable of this class is Algol, the type star of one of my groups nearly at the top of the descending arm, nearly on a level with the Crucian group on the other.

From these facts we learn that bright line variables with the Harvard Classification, B. A. F. K. M. should be stars increasing their temperature, while eclipsing variables marked B. A. F. K. N. should be decreasing their temperature.

The result of the preliminary inquiries so far has been very encouraging.

Stars with bright lines have been found in species represented on the ascending arm of the curve, and none on the descending side.

All variable stars with bright lines so far studied belong to the ascending side, eclipsing stars which do not show bright lines to the descending arm.

A great majority of the double stars without bright lines so far considered belong to the descending arm.

Details on all these points will be given when the research is further advanced.

It may be remarked that the danger of using the Harvard classifications is not the same for all the groups.

The normal stars which differ most in their physical state are the Antarian (ascending) and the Piscian (descending). These are differentiated by the adjacent letters M and N (A and Z would have been better).

One of the finest memoirs which has ever been written on stellar spectra is that of Düner on the two types, III*a*. and III*b*. of Vogel's classification. And a study of it will show that no two groups of spectra differ more widely than these.

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[5] *Astronomische Nachrichten*, No. 4847, vol. cxc., p. 193.

[6] Proc. Roy. Soc., 1888, p. 80.

[7] Proc. Roy. Soc., vol. xli., p. 278.

To secure simplicity I represented the two arms of the temperature curve of equal inclination, and to save space I used a narrow angle between them (although by all analogy the descending arm should fall less rapidly than the ascending one). The more the curve is flattened the less difference there will be in the physical conditions of stars on either side of the apex representing the highest temperature. These stars, therefore, will be difficult to classify, and even some of the conditions may vary in the Alnitamian, Crucian, and Achernian groups.

It is half-way up the two curves that the greatest confusion may arise if stars of the same name; (A, F, K) are treated as if their physical state were similar, α Cygni and Sirius, for instance, both A in the Harvard classification (H.3). NORMAN LOCKYER.

(*To be continued.*)

THE SERVICE OF SCIENCE.

A FEW months ago public attention was being directed by articles and letters in the *Morning Post* to the inadequate remuneration and prospects of scientific workers, particularly those engaged in research. The subject is one to which many columns of NATURE have been devoted since the foundation of this journal in 1869, but it cannot be too widely discussed if any serious effort is to be made to secure improved conditions in the future. The present is not perhaps the most propitious moment to ask for increased endowment of science and encouragement of discovery, but there are points relating to the position of science which can be stated as appropriately now as at any time. Some of these matters are referred to in an article on "Science and the State" in the October number of *Science Progress*, and the whole subject is under consideration by a committee of the British Science Guild.

The article in *Science Progress* is in continuation of one which was published in the April number, and its purpose is to offer a programme of steps toward the betterment of science in Britain and elsewhere. It is shown that the emoluments of scientific men are much below what might reasonably be expected for exceptional attainments; and the claim is made that the State should offer special rewards or pensions to investigators whose researches have proved of decided national or public advantage without being profitable to themselves.

The unsatisfactory positions of many professors and lecturers in our universities and other institutions of higher education, is due largely to the management of the institutions by commercial men who like to see fine buildings but are unable to understand the use of most of the work carried on in them. It comes as a surprise to such men to be told that in scientific circles usefulness is rarely adopted as the standard of value; and that even if not a single practical result is reached by an investigation, the work is worth doing if it enlarges knowledge or increases our outlook upon the universe. This proposition, of course, leaves the practical man cold; yet it is all that science desires to offer in justification of its activities. While the discovery of truth remains its single aim, science is free to pursue inquiries in whatever direction it pleases; but when it permits itself to be dominated by the spirit of productive application it will become merely the galley-slave of short-sighted commerce. Almost all the investigations upon which modern industry has been built would have been crushed at the outset if immediate practical value had determined what work should be undertaken. Science brings back new seeds from the regions it explores, and they seem to be nothing but trivial curiosities to the people who look for profit from research, yet from these seeds come the mighty trees under which civilised man has his tent, while from the fruit he gains comfort and riches.

Industrial research is concerned, not with the discovery of truth, but with the production of something which will be of direct service to man and from which pecuniary profit may be secured: it is the province of the inventor rather than that of the man of science. Such research and that carried on with no ulterior motive are complementary to one another. Science has done its part when it has made a new discovery; constructive engineering renders good service when it shows how the discovery may be chained to the advancing chariot of industry. To foresee the possibilities of a discovery, to transform a laboratory experiment into the mechanical plant of a large works, or to apply it to the needs of ordinary life, require aptitudes not commonly possessed by the scientific investigator. The engineer usually has such practical purposes in mind; discoveries are to him things to be used and not ends in themselves, as they are to the man of science. He seeks not so much to know Nature as to circumvent her; and the research which he undertakes or organises has for its object the artificial preparation of substances which are naturally rare, the production of a new process or the improvement of an old, the design of machines which will increase his power over her, and of instruments which will enable him to laugh at limitations of time and space.

Research is necessary for these advances, but the spirit in which it is carried on is essentially different from that of the scientific worker. The engineer or the inventor first of all perceives a need and then endeavours to devise a means of meeting it. If he is of a scientific type of mind he will make an accurate analysis of the conditions to be fulfilled, and then design his machine or instrument to fulfil them; but the usual way is to find practically what will perform the required functions, and to leave experience or scientific knowledge to indicate how improvements may be effected.